DEVELOPMENT OF CAPACITY RESERVATION CONTRACT WITH ONE SUPPLIER AND ONE RETAILER

by

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Industrial and Manufacturing Engineering

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July 2021

AUTHOR’S DECLARATION

I, Zin Wai Wai Htet, certify that the research for this thesis was conducted in compliance with the Asian Institute of Technology's regulations. The material given was created by me because of my own original study, and any external sources that were used were cited. It is unique and has never been submitted to another institution for the purpose of obtaining a different degree or certificate. This is an exact copy of the thesis, complete with final modifications.

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ACKNOWLEDGMENTS

In doing the research, I would like to thank my advisor, Dr. Huynh Trung Luong, chair of the thesis committee, who has given through my study with clear explanation and valuable knowledge. I am grateful for the kindness and grateful gratitude here.

Thank you to Dr. Pisut Koomsap and Dr. Mongkol Ekpanyapong, as the members of thesis examination committee, for giving advice and suggestions as well as correcting flaws in the thesis.

Thank you to the staffs who kindly provided valued ideas for this thesis. Thank you to all friends in Industrial Systems Engineering department who have supported, shared happiness, and helps.

Moreover, I would like to thank for the care and encouragement of the dearly loved family members who supported the study so that this research was able to be carried out in the time.

ABSTRACT

This research investigates supply chain coordination in a two-stage supply chain with the capacity reservation contract. Under the capacity reservation contract, the supplier announces the prices and after that, the retailer pays a reservation fee under uncertain demand. When the demand information is realized, the retailer exercises the reserved capacity by actual order. To investigate coordination, the mathematical models are developed and the demand in each period is assumed to be uniformly distributed. The research also analyzes how the parameters affect the firms' behavior in such a way that coordination and fair profits can be achieved. This research finds that the capacity reservation contract can coordinate the whole supply chain.

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LIST OF ABBREVIATIONS

K	=	reserved capacity
K_0	=	constructed capacity
w_0	=	unit reservation price
w_e	=	unit exercised price
$w_{e\,x}$	=	unit excess exercise price
w_r	=	unit selling price of retailer
c_c	=	supplier's unit constructing cost
c_p	=	supplier's unit production cost
g	=	unit shortage cost
z	=	realized demand during selling period
$\pi^R(.)$	=	profit function of retailer
$\pi^M(.)$	=	profit function of manufacturer
$\pi_{CSC}(.)$	=	centralized system's profit
$\pi_{DSC}(.)$	=	decentralized system's profit

CHAPTER 1
INTRODUCTION

1.1. Background of the Study

The supply chain is made up of interlinked businesses that come together to generate value through the production of goods and services that are then distributed to end users. Suppliers, manufacturers, transporters, and buyers are frequently found in a supply chain (Giannoccaro,2018). Researchers and practitioners from numerous disciplines have been paying close attention to supply chain management.

Logistics, inventories, purchasing, purchasing, production scheduling, intra- and inter-organizational connections, and performance measurement are all part of a supply chain. Many publications and case studies on supply chain in many industries have sparked further interest in supply chain research. Supply chains are made up of a variety of activities, functions, and time periods.

The functionality of a supply chain's partners is one of the most important aspects that determines its production value. To increase the supply chain's system results, all members must work as part of a single system and collaborate with one another, so coordination must be prioritized (Burgess et al.,2006).

In centralized supply chains, all information and demand should be communicated among the participants, and the information flow should be well established. In a centralized supply chain, planner in charge (a single decision maker) makes all of the choices and ensures that all supply chain members are treated fairly.

A decentralized supply network, on the other hand, is based on personal logical choices made by members with the goal of increasing profits without selecting the best option for the entire market. A decentralized supply network, on the other hand, is based on personal logical choices made by members with the goal of increasing profits without selecting the best option for the entire market.
A decentralized supply network, on the other hand, is based on personal logical choices made by members with the goal of increasing profits without selecting the

best option for the entire market. Although member activities can result in double marginalization, lowering overall supply chain efficiency, forming a relationship among associates and exchanging data across the supply chain can help to increase productivity.

A very well contract can let self-interested individual parties coordinate their decisions to maximize the income of a centralized supply chain (Pezeshki et al., 2013). Capacity management is a difficult problem in the semiconductor, telecommunications, and optoelectronics industries, because capacity expansion necessitates huge upfront capital inputs and long lead times (Wu et al., 2005). In particular in a decentralized supply chain, the capacity management is more challenging.

The reason is that the upstream supplier or manufacturer starts to use policies of enhancing capability to reduce the danger of demand uncertainty and the buyer or merchant can face supply shortage in fulfilling the market demand, consequently, this situation makes the supply chain perform poorly. When the decentralized supply network generates total profit similar to the centralized system, supply chain coordination is achieved.

To achieve this, several coordination mechanisms are in place to assist supply chain members in making the best decisions possible (Cachon,2002). The rapid advancement of technology has reduced the selling season and become more demand unpredictability.

To deal with the difficulty of a short selling period, retailers typically place orders ahead of time based on preliminary demand estimates. However, because to the significant fluctuation of demand, they may face the risk of overstocking or underproduction. Retailers typically mitigate this risk by deferring order choices, allowing them to increase demand forecasting accuracy. However, suppliers are unable to meet store demand in a timely manner (Li et al.,2014).

As a result, suppliers frequently use the capacity reservation contract to gather transaction data from merchants and plan capacities ahead of time. The risk-sharing element of the capacity reserve contract pushes manufacturers to grow their capabilities while also generating future income for retailers.

Retailers are required to book capacity in front under a capacity reservation contract because earlier agreement reduces costs and avoids potential shortages. This study will look into the best approach for a supply chain with a vendor and one buyer in a decentralized system under a capacity reservation contract, as well as the effectiveness of the supply chain in a centralized system as a benchmarking.

1.2. Statement of the Problem

In traditional capacity reservation contract, a supplier requests that a merchant place an order ahead of time and the supplier would not increase capacity beyond the reserved quantity (Li et al., 2020). Following this line, a new sort of capacity reserve contract is proposed in which the retailer, who faces stochastic demand, pays a reservation cost ahead for future necessity before placing a fixed order. Li et al. (2014) indicated that the supplier is committed to build the capacity level that the buyer has requested. However, the vendor might consider adding additional capacity based on his opinion.

So, we assume that the supplier can construct a capacity which is different from the reserved capacity of the retailer. When the constructed capacity is not fully utilized, the remaining capacity have zero salvage value. If the retailer orders higher than his reserved quantity, the supplier can accept if his constructing capacity is higher than the reserved quantity of the retailer. The part of demand that cannot be fulfilled will be lost, and hence, the retailer will have to bear lost sales cost for this situation.

1.3. Objective of the Study

The target of this research is to determine optimal decisions of one supplier and one retailer in decentralized system under a capacity reservation contract. As a benchmark, the contract model proposed in this research will be compared with the centralized supply chain.

To maximize each individual's expected profit, the retailer decides his optimal reserved capacity and the manufacturer decides his optimal constructed capacity. A coordination mechanism is designed which can make the supply chain profit increases. The ability of the contract to coordinate the supply chain will also be investigated.

1.4. Scope and Limitations

The following characteristics of the system will be examined throughout the research;

1. The chain with two-stage having one supplier and one retailer
2. The retailer faces uncertain demand
3. Unfulfilled demand will be lost
4. The constructed capacity of the manufacturer might not be the same as the reserved capacity of the retailer
5. Excess capacity has no salvage value
6. The unused constructed capacity of the supplier has zero salvage value.
7. The retailer places the order in advance before the selling season
8. If the retailer's order is less than his reserved quantity, the reservation price will not be reimbursed.

CHAPTER 2
LITERATURE REVIEW

This study is to come up with optimal decisions of one upstream member and one downstream member in a two-stage one period supply chain so that each player's profit would be maximized under a capacity reservation contract for a stochastic demand. The prior studies that provide related elements about supply chain coordination and capacity reservation contracts are the subject of the literature study.

2.1. Supply Chain Coordination

Many supply chain researchers were constantly attempting to improve the total efficiency of the supply network management. Coordination analysis can help with the difficulty of managing interactions between supply chain partners. The absence of coordination in the system results in poor performance.

As a result, erroneous projections, low-capacity utilization, overproduction, issues of service, stock shifts, stock prices, time to market, fulfilling reaction, durability, client service, and client service are all possible outcomes (Ramdas & Spekman, 2000).

The different categories of coordination are coordination’s role in supply chain and set of models, coordination between several functions and at various steps of supply chain, techniques of supply chain cooperation, empirical case studies in supply chain cooperation. Among the different categories of coordination, coordination mechanisms are classified into four types.

Supply chain contracts, information technology, knowledge exchange, and cooperative decision making are all examples of these. As mentioned above, the relationships among the partners of system can be managed by coordination methods. The productivity of supply chain is improved by utilizing coordination methods (Arshinder et al., 2008).

Furthermore, three types of operational coordination are considered: merchant-vendor coordination, production-distribution coordination, and inventory-distribution coordination (Thomas & Griffin, 1996). For a coordinating mechanism, Li & Liu (2008) proposed an expanded newsboy model with a vendor's restricted requested amount and consider profit-allocating procedure in a network containing a store and a manufacturer.

Because the buyer has too much stock from his first order amount and the manufacturer faces the risk of cost for reservation capacity and production, to coordinate supply chain in decentralized system, the researchers employ both the retailer's optimized first order quantity and the manufacturer's optimized reserve capacity. They came up with a coordinated response in which the producer uses a tiny savings tactic to urge the retailer to place two orders in most efficient volumes. The forecasted profit rises in result of cooperation.

Thomas and Griffin (1996) investigated a system in which businesses might save operational costs by synchronizing the planning of three key supply chain stages: purchasing, manufacturing, and transportation. They reviewed the coordinated planning between multiple steps, then discussed on how to reduce operating cost by coordination production schedules and order.

Lin & Kroll (1997)examined polices of quantity discount: all-unit and incremental as coordinating methods. They investigated at the single-item newsboy dilemma using a dual measure of performance and a quantity discount. The goal is to boost the estimated profit while ensuring chance of reaching a specific profit level does not fall below a set risk level.

In a just-in-time scenario, Zimmer (2002) develops a firm item and delivery scheduling model. The goal is to find a coordinating process that allows a decentralized organizations to run as well as a centralized system. Chung and Flynn (2001) compare the traditional newsboy approach to a reactive production approach that leverages traditional newsboy formulas. An anticipating stage and a responsive stage are two stages in the production process.

In the reactive stage, production takes place with full understanding of the physical demand and may thus respond to it. The purpose is to find the appropriate purchase quantity lowering in a buyer's estimated total expenses. Zhou et al. (2017) investigate the effects by GPO that includes one GPO and two producers operating in number with whole-sale pricing contracts. They demonstrated that group pricing can help the supply network by sharing information partly from the lower-precision maker instead of all parties.

2.2. Supply Chain Contracts

Supply network coordination via contracts is commonly used to reduce supply network inefficiency and align supply chain participants' objectives. In a two-stage network, both participants often agree on costs, promotions, purchasing amounts, order quantities, quality of products, and refund policy through a contract (Chen et al., 2009).

Supply chain contracts have been used in many research articles to improve system performance and maximize supply chain revenues. Several research papers have been published on supply contract coordination such as revenue-sharing, option, quantity flexibility, capacity reserve, cost-sharing, wholesale price discount, buy-back, and so on (Chen et al., 2009).

In a model, Cachon & Lariviere (2005) provided a revenue-sharing agreement, with revenues defined by the number and price of each retailer's purchases. They demonstrated that a single revenue-sharing agreement, when compared to coordination by numerous other contracts, is able to cooperate a system with numerous noncompetitive merchants, although the merchants have distinct income purposes.

Wang and Tsao (2006) propose a single-period two-stage agreement model that includes bidirectional choices for bidirectional adjustment. They looked at the model from the dealer's viewpoint, computed the function of profit for the buyer, and demonstrated the dealer's best rules for the first order and choices. When demand is evenly distributed, they achieved equations with a closed form to calculate the best first order quantity for the consumer and the best number of purchasing options.

At the selling season, Hu et al. (2014) assumes a decentralized supply chain with single retailer and single manufacturer and two orders, where the retailer placed the original order amount while conversing with the manufacturer about an optional order amount. The demand of the store, the production yield of the producer, and the current pricing are all stochastic.

The authors determined the manufacturer's ideal production amount and defined the best ordering policy for a retailer. To characterize the ideal replenishment strategy structure for the buyer, Lian & Deshmukh (2009) suggested a Rolling Horizon Planning (RHP) contract with a finite-horizon dynamic programming model. The goal is to come up with a good ordering policy that will reduce the total cost. They showed how to compute each interval of the rolling horizon's order volume using heuristic methods. Yang and Wu (2016) investigated the performance of decentralized system with buyer and provider.

They looked at bidirectional contracts from both sides and came up with a formula which is a closed-form for the dealer's best choice. In a specified fashion, the options which is bidirectional are used as call and put options. As a result, they were able to derive solutions with closed form for the optimized amount of original order and purchased options.

Park and Kim (2014) examine a contract for multi-period capacity reservations between a buyer, numerous heterogeneous providers, who create and replenish the product in accordance with the contract's terms. A rolling-horizon implementation methodology is provided for the most efficient application of the models.

2.3. Capacity Reservation Contracts

By offering an appropriate contract, the enterprises can build a coordination mechanism. The general issues with a capacity reserve for supply chain participants are that the supplier runs dangers of having too much capacity, while the buyer runs danger of having too much inventory at the conclusion of the selling period (Pezeshki et al., 2013).

In the situation of demand uncertainty, Hazra & Mahadevan (2009) explore the procurement issue of a buyer through a capacity reserve contract in a supply network with a buyer and numerous providers. The buyer must decide how much capacity should be purchased via a capacity reserve contract, as well as how many suppliers should be chosen and allotted.

Closed-form solutions for a technique of equitable capacity distribution among the chosen vendors were created by the researchers. They calculate the capacity reservation price and show that expanding the number of pre-qualified providers does not bring considerable advantages to the customer.

Pezeshki et al. (2013) looked into how to use contracts to coordinate a high-tech product created by a triadic supply chain, taking into account the rate of manufacturing, which is limited to the capacity built up throughout the manufacturing period and order quantity of a store. In the case of both complete and partial information updates, they offered capacity reservation contract, a partially deductible reservation (PARD) contract, and a reservation contract with cost and revenue sharing contract (RCRS) contract.

They also looked at how members acted in both forced and voluntary compliance situations. Wu (2005) looked at a decentralized supply chain with two members that are completely independent, a vendor and a buyer, who were bound by a quantity flexibility contract. If there are no coordination mechanisms in place, the two members separate optimized amount judgments according to respective demand information, costs.

In order to maximize the effectiveness of a decentralized supply chain, each member's two problems should be coordinated. The researchers concentrated in terms of quantity flexibility contracts, lead times, transfer prices and created a novel type of supply contract that uses a mix of quantity flexibility and a quick response system to alleviate the system's inefficiencies.

Erkoc and Wu (2005) used channel coordination capacity reserve contracts with an exogenous wholesale price to study market size and demand fluctuation. When demand data is only partly modified, they looked into how the partially deductible (PARD) and cost-sharing (COSH) contracts work. They demonstrated that early commitment contracts may benefit both the provider and the buyer if certain requirements were met.

Jin and Wu (2007) looked at a capacity reservation contract known as a deductible reservation (DR) contract, in which clients book capability in the future from the vendor and vendor expands capacity by outsourcing. They looked at the DR contract for a single manufacturer and a single customer, as well as a single manufacturer and several consumers.

Customers must pay an upfront cost when making a reservation under the DR contract, the take-or-pay contract, on the other hand, does not compel payment until the actual demand is met. There was also a comparison of the DR contract and the take-or-pay reservation contract. As a result, suggested contracts have an advantage over traditional contracts when there are several customers.

Pezeshki et al. (2013) explore the fashion industry's a two-way supply chain. They proposed a revenue sharing reservation contract with penalty (RSRP) as a coordinating procedure to match pricing and capability decisions in a voluntary compliance environment.. Pezeshki et al. (2013) explore the fashion industry's dyadic supply chain. In a non compliance environment, they proposed a revenue sharing reservation contract with penalty (RSRP) as a coordinating technique to match pricing and capacity decisions.

They modified this contract to make diverging supply chain to enhance performance of whole system. When faced with a stochastic and price-dependent demand, they assumed that the provider should decide on capacity building and duration for production, while price and order quantity should be decided by the customer. As a result, RSRP demonstrated toughness and adaptability, and the capacity to connect retailer actions in system’s overall benefit, demonstrating that it has sufficient potential as a coordinating mechanism in diverging supply chains.

Li et al. (2014) looks at a supply network with one supplier and one retailer with stochastic demand. Under the capacity reserve contract, in which the buyer estimates his demand, retailer estimates his demand, the optimal decisions of both sides are studied in both centralized and decentralized systems. A reservation fee is paid by the retailer to the provider for the matching capacity, and the vendor constructs capacity equal to or more than the amount reserved by the retailer.

Using expected demand, the provider builds capacity with a long setup time. In this study, the retailer decides his ordering amount in the selling season and if the order amount is less than the retailer's reserve capacity, it is purchased with an exercise price. Alternatively, a greater price is paid for the surplus quantity. The supplier agrees to build up to the retailer's specified level. In addition, the supplier may build capacity that exceeds the buyer's requested amount. If the ordered amount exceeds the supplier's construction capability, the provider must promptly outsource to satisfy the high demand.

According to Mathur and Shah (2008), many high-tech enterprises are in risk of losing demand due to insufficient supplier capacity building. As a result, supply chain stakeholders made capacity investment decisions through contracts that included risk-sharing arrangements. They created a supply chain with a single supplier and a single manufacturer, in which the vendor must develop capacities before manufacturing, and the manufacturer must reserve capacity for his suppliers.

A price compliance regime is used to represent the supply chain, utilizing capacity as a contract parameter. Various penalties criteria are explored for their impact on a client's capacities selection, supply chain efficiency, and relative supply chain profit allocation across partners.

Li et al. (2013) studied a single-interval supply chain with a vendor who supports unique items and a buyer who experiences stochastic demand. A Stackelberg game is utilized as the negotiation procedure for capacity reserve policy since merchant is the follower and the supplier is the leader.

The goal is to create a capacity reserve strategy that permits the merchant and the supplier to enlarge predicted revenues. The authors look at the best policy for capacity increase (or reserve contract) in cases where the capacity reservation policy with an exogenous reservation price is announced by the supplier (or additional capacities), and then show how the reservation price (or extra capacity) affects the best selections.

2.4. Information Sharing

Among of the most crucial parts of supply network coordination is sharing information. Efficient management is critical because today's competition is no longer between businesses, but rather between supply networks. To cut pricing and increase clients service levels, all components of a whole supply system communicate their knowledge properly and coordinate replenishment of their stocks, production decisions in the face of unpredictability in demand.

Information flows from downstream firms to their upstream counterparts include information on sales and demand projections. Upstream firms offer order state information to their partners in the chain. Furthermore, exchanging data among members includes data on production quality, completion dates, and production capabilities (Kumar & Pugazhendhi, 2012).

Vendor managed inventory (VMI), cross-docking, and quick response are examples of how information exchange in a supply chain can strengthen business relations (QR). Information sharing between supply chain partners should be improved to reduce the bullwhip impact and uncertainty.

Using Electronic Data Interchange (EDI) technology to expand information sharing vertically can increase supplier shipping performance and the supply network system's overall performance (Yu et al., 2001). A conventional supply chain model was studied by Moinzadeh (2002), which consisted of a product, a vendor, and M identical retailers.

Each buyer's demand obeys a Poisson process. Each merchant follows the (Q,R) policy when placing orders with the provider. They first presented a vendor's replenishing policy that includes details about retailers' stock positions. After that, they produced a precise study for the functioning measures of such systems. As a result, they compared the suggested model's performance to that of models that make no decisions based on received data.

Bourland et al. (1996) looked at a system which has two levels with a vendor and client. For one specific item, the two companies adopt a regular periodic base-stock policy, but their equal-length production cycles do not always coincide. Both parties keep inventory to mitigate the impacts of unpredictable orders and deliveries. In response, the supplier provides supply with a limitless capacity. Only the final assembly plant has final demand, which it conveys to the component plant during its order cycle.

CHAPTER 3
MATHEMATICAL MODEL DEVELOPMENT

The study will begin with the creation of a mathematical formula based on a capacity reservation contract. For everyone in the company, an expression for predicted profit will be created from this model. Finally, the model will be numerically tested to see how the parameter values affect the total earnings of buyer and proposed contract's provider.

3.1 Notations and Assumptions of Mathematical Model

A single vendor and a single buyer make up the modelling. When faced with unpredictable demand, the merchant allocates capacity **K** for future at a reservation fee $\mathbf{w_0}$ by sharing advance demand information before a fixed order. Based to The initial capacity allocated by the retailer, the vendor should construct the capacity at unit cost $\mathbf{c_c}$ prior to retailer's firm orders as the installation of capacity requires a significant lead time. The supplier may construct capacity $\mathbf{K_0}$ which is different (greater) from the reserved capacity K of the retailer.

When the selling period comes, the dealer has more demand updated data and then places a firm order. According to the real demand, the retailer can order more or less than the initial reserved capacity order.

If demand is not greater than or balance reserved capacity, retailer will order as the demand, so the retailer doesn't need to pay excess price per unit, just pay $\mathbf{w_e}$ exercise price per unit.

If the demand is between reserved quantities and constructed quantities, the retailer will order quantities as the demand but the retailer have to pay excess price $\mathbf{w_{ex}}$ for the excess quantities from the reserved quantities.

If the demand is more than the constructed quantities, the retailer met the shortage case, so he orders the constructed quantities and he pays the shortage cost for the case.

The following notations are used in this research.

K= reserved capacity

K_0=*constructed capacity*

w_0= *Unit reservation price*

w_e= *Unit exercised price*

w_{ex}= *Unit excess exercise price*

w_r= *Unit selling price of retailer*

c_c = *Supplier's unit constructing cost*

c_p = *Supplier's unit production cost*

g = *Unit shortage cost*

z = *realized demand during selling period*

$\pi^R(.)$ = *Profit function of retailer*

$\pi^M(.)$ = *Profit function of manufacturer*

$\pi_{CSC}(.)$ = *centralized system's profit*

$\pi_{DSC}(.)$ = *decentralized system's profit*

[r - m , r + m]= demand range

Profit function of each member at first stage

Profit function for retailer= reservation cost

π_1^R (K, K_0)= $-w_0K$

Profit function for manufacturer= revenue from reserved quantity-capacity constructing cost

π_1^M (K, K_0)= $w_0K - K_0c_c$

Profit function of each member at second stage

We have:

$f(z) = \{\frac{1}{(r+m)-(r-m)}\ , \quad r - m \le z \le r + m\ \ 0\ , \qquad otherwise$

or

$f(z) = \frac{1}{2m}$, $z \in [\ r\text{-}m\ ,\ r\text{+}m]$

Cumulative distribution function of demand is

$F(z)=\{0 \quad , z \le r - m\ \ \frac{z-(r-m)}{(r+m)-(r-m)},\ \ r-m \le z \le r+m\ 1\ \ ,\ \ z \ge r+m$

$F(z)= \frac{z-r+m}{2m}$, $z \in [r\text{-}m\ ,\ r\text{+}m]$

The following are some examples of probable scenarios based on realized demand (z):

Case I: r – m < z ≤ K

Case II : K < z < K_0

Case III: $K_0 \leq z < r + m$

Each scenario's profitability calculation will be derived in the following sections.

Case I: r – m < z ≤

Since realized demand is not greater than or same to *K*, retailer will order z. Retailer purchases at exercise price for units in the realized demand. The manufacturer will produce the order quantities from retailer.

The following are the profit functions for both the retailer and the manufacturer:

- Profit function for retailer = Sale revenue - cost of order quantities

  π_2^R (K, K_0) = $w_r z - w_e z$

- Profit function for Manufacturer = income from retailer's order - cost of production

  π_2^M(K, K_0)= $w_e z$ - $c_p z$

Case II: K < z < K_0

When realized demand z is between K and K_0, the retailer will order z in which the excess amount (z – K) will be charged at excess exercise price which is higher than exercise price. The manufacturer will produce the order quantity from retailer.

The following are the profit functions for both the retailer and the manufacturer:

- Profit function for retailer = Sale revenue – cost of order quantities

  π_2^R (K, K_0)= $w_r z - [w_e K + w_{ex}(z - K)]$

- Profit function for Manufacturer = income from order quantities- cost of production

  $\pi_2^M(K, K_0)$= $[w_e K + w_{ex}(z - K)] - c_p z$

Case III: $K_0 \leq z < r + m$

When realized demand is between K_0 and r + m, the retailer will order K_0 and pays excess exercise price for the excess amount (K_0 – K). Due to unfulfilled demand, the retailer is experiencing a shortage. The vendor will produce the order quantity from retailer.

The following are the profit functions for both the retailer and the manufacturer:

- Profit function for retailer = Sale revenue – cost of order quantities - shortage cost

  π_2^R (K, K_0)= $w_r K_0 - [w_e K + w_{ex}(K_0 - K)] - g(z - K_0)$

- Profit function for Manufacturer =income from order quantity - cost of production

  $\pi_2^M(K, K_0) = [w_e K + w_{ex}(K_0 - K)] - c_p K_0$

3.1.1 Overall Retailer's Profit

The profit function of the overall retailer is the profit addition in the first stage and profit in the second stage.

$\pi^R(K, K_0)$= $-w_0 K + E[\pi_2^R\ (K, K_0)]$

The retailer's expected profit in the second stage, $E[\pi_2^R$ $(K, K_0)]$, can be derived as follows.

$E[\pi_2^R$ $(K, K_0)]$= $\int_{r-m}^{K}(w_r z - w_e z)f(z)dz + \int_{K}^{K_0}\{w_r z - [w_e K + w_{ex}(z - K)]$

$\}f(z)dz + \int_{K_0}^{r+m}\{w_r K_0 - [w_e K + w_{ex}(K_0 - K)] - g(z - K_0)\}\ f(z)dz$

$=\int_{r-m}^{K}\{(w_r - w_e)z\}\{\frac{1}{2m}\}dz + \int_{K}^{K_0}\{(w_r - w_{ex})z + (w_{ex} -$

$w_e)K\}\{\frac{1}{2m}\}dz + \int_{K_0}^{r+m}\{(w_r - w_{ex} + g)K_0 + (w_{ex} - w_e)K - gz\}\{\frac{1}{2m}\}dz$

$=\frac{\{(w_r-w_e)[(K^2-(r-m)^2]\}+\{(w_r-w_{ex})[K_0^2-K^2]\}-\{g[(r+m)^2-(K_0)^2]\}}{4m} +$

$\frac{\{[(w_{ex}-w_e)K](K_0-K)\}+\{[(w_r-w_{ex}+g)K_0](r+m-K_0)\}+\{[(w_{ex}-w_e)K](r+m-K_0)\}}{2m}$

Hence, the retailer's profit function can be determined as follows.

π^R (K, K0)= $-w_0 K + E[\pi_2^R\ (K, K_0)]$

$$= -w_0 K + \frac{\{(w_r-w_e)[(K^2-(r-m)^2]\}+\{(w_r-w_{ex})[K_0^2-K^2]\}-\{g[(r+m)^2-(K_0)^2]\}}{4m} + \frac{\{[(w_{ex}-w_e)K](K_0-K)\}+\{[(w_r-w_{ex}+g)K_0](r+m-K_0)\}+\{[(w_{ex}-w_e)K](r+m-K_0)\}}{2m}$$

3.1.2 Overall Manufacturer's Profit

Overall manufacturer's profit function is the addition of profit in first stage and profit in second stage.

π^M (K, K0) = $w_0 K - K_0 c_c + E[\pi_2^M\ (K, K_0)]$

The manufacturer's expected profit in the second stage, $E[\pi_2^M\ (K, K_0)]$, can be derived as follows.

$E[\pi_2^M\ (K, K_0)]= \int_{r-m}^{K} (w_e z - c_p z) f(z)dz + \int_{K}^{K_0} \{[w_e K + w_{ex}(z-K)] - c_p z\}$
$f(z)dz + \int_{K_0}^{r+m} \{[w_e K + w_{ex}(K_0 - K)] - c_p K_0\} f(z)dz$

$= \int_{r-m}^{K} (w_e - c_p) z \frac{1}{2m} dz + \int_{K}^{K_0} \{(w_{ex} - c_p)z + (w_e - w_{ex})K\} \frac{1}{2m} dz + \int_{K_0}^{r+m} \{(w_{ex} - c_p)K_0 + (w_e - w_{ex})K\} \frac{1}{2m} dz$

$= \frac{\{(w_e-c_p)[K^2-(r-m)^2]\}+\{(w_{ex}-c_p)(K_0^2-K^2)\}}{4m} + \frac{\{[(w_e-w_{ex})K](K_0-K)\}+\{[(w_{ex}-c_p)K_0](r+m-K_0)\}+\{[(w_e-w_{ex})K](r+m-K_0)\}}{2m}$

Hence, the manufacturer's profit function can be determined as follows.

$\pi^R\ (K, K_0) = w_0 K - K_0 c_c + E[\pi_2^M\ (K, K_0)] = w_0 K - K_0 c_c + \frac{\{(w_e-c_p)[K^2-(r-m)^2]\}+\{(w_{ex}-c_p)(K_0^2-K^2)\}}{4m} + \frac{\{[(w_e-w_{ex})K](K_0-K)\}+\{[(w_{ex}-c_p)K_0](r+m-K_0)\}+\{[(w_e-w_{ex})K](r+m-K_0)\}}{2m}$

3.2 The Optimal Reservation Capacity of the Retailer

From the profit function of the retailer,

$\pi^R(K) = -w_0 K + E[\pi_2^R\ (K, K_0)]$

$= -w_0 K + \frac{\{(w_r-w_e)[(K^2-(r-m)^2]\}+\{(w_r-w_{ex})[K_0^2-K^2]\}-\{g[(r+m)^2-(K_0)^2]\}}{4m} + \frac{\{[(w_{ex}-w_e)K](K_0-K)\}+\{[(w_r-w_{ex}+g)K_0](r+m-K_0)\}+\{[(w_{ex}-w_e)K](r+m-K_0)\}}{2m}$

We have:

$\frac{d\pi^R}{dK} = -w_0 + \frac{2(w_r-w_e)K-2(w_r-w_{ex})K}{4m} + \frac{(w_{ex}-w_e)K_0-2(w_{ex}-w_e)K+(w_{ex}-w_e)(r+m)-(w_{ex}-w_e)K_0}{2m}$

$= -w_0 + \frac{(w_r-w_e)K-(w_r-w_{ex})K+(w_{ex}-w_e)K_0-2(w_{ex}-w_e)K+(w_{ex}-w_e)(r+m)-(w_{ex}-w_e)K_0}{2m}$

$= -w_0 + \frac{(w_r-w_e-w_r+w_{ex}-2w_{ex}+2w_e)K+(w_{ex}-w_e)(r+m)}{2m}$

$= -w_0 + \frac{(w_e-w_{ex})K+(w_{ex}-w_e)(r+m)}{2m}$

$$\frac{d^2\pi^R}{K^2} = \frac{w_e - w_{ex}}{2m}$$

It is noted that $w_e - w_{ex} < 0, therefore\ \frac{d^2\pi^R}{dK^2} < 0$

So, $\pi^R(K)$ is a concave function with respect to K.

Then the optimal reserved capacity K is the unique solution of $\frac{d\pi^R}{dK} = 0$. Hence,

$\frac{d\pi^R}{dK} = -w_0 + \frac{(w_e - w_{ex})K + (w_{ex} - w_e)(r+m)}{2m}$ =0

$\frac{(w_e - w_{ex})K^* + (w_{ex} - w_e)(r+m)}{2m} = w_0$

$(w_e - w_{ex})K + (w_{ex} - w_e)(r + m\ ) = \ 2mw_0$

$(w_e - w_{ex})K = 2mw_0 - [(w_{ex} - w_e)(r + m)]$

$$K = \frac{2mw_0 - [(w_{ex} - w_e)(r + m)]}{(w_e - w_{ex})}$$

$$K = r + m - \frac{2mw_0}{(w_{ex} - w_e)}$$

So,

$$K^* = r + m - \frac{2mw_0}{(w_{ex} - w_e)}$$

It is noted that K must be positive, therefore, the following condition must hold true:

$$r + m \geq \frac{2mw_0}{w_{ex} - w_e}$$

3.3 The Optimal Constructing Capacity of the Manufacturer

From the profit function of the manufacturer,

$\pi^M(K_0)$= $w_0K - K_0c_c + E[\pi_2^M\ (K, K_0)]$

= $w_0K - K_0c_c$+$\frac{\{(w_e - c_p)[K^2 - (r-m)^2]\} + \{(w_{ex} - c_p)(K_0^2 - K^2)\}}{4m} +$

$\frac{\{[(w_e - w_{ex})K](K_0 - K)\} + \{[(w_{ex} - c_p)K_0](r + m - K_0)\} + \{[(w_e - w_{ex})K](r + m - K_0)\}}{2m}$

We have:

$\frac{d\pi^M}{dK_0}$= $-c_c + \frac{2(w_{ex} - c_p)K_0}{4m} + \frac{(w_e - w_{ex})K + (w_{ex} - c_p)(r+m) - 2(w_{ex} - c_p)K_0 - (w_e - w_{ex})K}{2m}$

=$-c_c + \frac{-(w_{ex} - c_p)K_0 + (w_{ex} - c_p)(r+m)}{2m}$

$\frac{d^2\pi^M}{dK_0^2}$=$\frac{-(w_{ex} - c_p)}{2m}$

It is noted that $-w_{ex} + c_p < 0, therefore, \frac{d^2\pi^M}{dK_0^2} < 0$

So, $\pi^M(K_0)$ is a concave function with respect to K_0 .

Then the optimal constructed capacity K_0 is the unique solution of $\frac{d\pi^M}{dK_0} = 0$. Hence,

$\frac{d\pi^M}{dK_0}$ = =$-c_c + \frac{-(w_{ex} - c_p)K_0 + (w_{ex} - c_p)(r+m)}{2m} = 0$

$$\frac{-(w_{ex} - c_p)K_0 + (w_{ex} - c_p)(r + m)}{2m} = c_c$$

$$-(w_{ex}-c_p)K_0+\left(w_{ex}-c_p\right)(r+m)=2mc_c$$
$$-(w_{ex}-c_p)K_0=2mc_c-\left[\left(w_{ex}-c_p\right)(r+m)\right]$$
$$K_0=\frac{2mc_c-\left(w_{ex}-c_p\right)(r+m)}{(c_p-w_{ex})}$$
$$K_0=r+m-\frac{2mc_c}{w_{ex}-c_p}$$

So,

$$K_0^*=r+m-\frac{2mc_c}{w_{ex}-c_p}$$

It is noted that K_0 must be positive, therefore, the following condition must hold true:

$$r+m\geq\frac{2mc_c}{w_{ex}-c_p}$$

Decision Analysis:

It is noted that

The optimal solution of K, $K^*=r+m-\frac{2mw_0}{(w_{ex}-w_e)}$

The optimal solution of K_0, $K_0^*=r+m-\frac{2mc_c}{w_{ex}-c_p}$

Let's analyze the decision of the manufacturer according to K^*

If $K_0^*\geq K^*$ *then,* the constructed capacity of the manufacturer will be

$$K_0=K_0^*$$

If $K_0^*<K^*$ $then,$

$$K_0=K^*$$

So,

$$K_{0d}^*=\{K_0^*\ if\ K_0^*\geq K^*\ K^* if K_0^*<K^*$$

or

$$K_{0d}^*=Max\{K^*,K_0^*\}$$

In the case the manufacturer is the leader in the contract, the manufacturer can decide on the constructed capacity and his constructed capacity will be the optimal solution of his profit function, K_0^*.

Let's analyze the decision of the retailer according to K_0^*

If $K^* \leq K_0^*\ then,$

$$K = K^*$$

If $K^* > K_0^*\ then,$

$$K = K_0^*$$

So,

$$K = \{K^* if\ K^* \leq K_0^*\ K_0^*\ if\ K^* > K_0^*$$

or

$$K = Min\{K^*, K_0^*\}$$

3.4 The Total Profit of the Whole Supply Chain

The total profit function of the whole supply chain system is derived as follows.

$$\pi_{DSC}(K, K_0) = \pi^R(K, K_0) + \pi^M(K, K_0)$$

$$=\Big(-w_0K + \frac{\{(w_r - w_e)[(K^2 - (r-m)^2]\} + \{(w_r - w_{ex})[K_0^2 - K^2]\} - \{g[(r+m)^2 - (K_0)^2]\}}{4m} + \frac{\{[(w_{ex} - w_e)K](K_0 - K)\} + \{[(w_r - w_{ex} + g)K_0](r+m-K_0)\} + \{[(w_{ex} - w_e)K](r+m-K_0)\}}{2m}\Big) + \Big(w_0K - K_0c_c + \frac{\{(w_e - c_p)[K^2 - (r-m)^2]\} + \{(w_{ex} - c_p)(K_0^2 - K^2)\}}{4m} + \frac{\{[(w_e - w_{ex})K](K_0 - K)\} + \{[(w_{ex} - c_p)K_0](r+m-K_0)\} + \{[(w_e - w_{ex})K](r+m-K_0)\}}{2m}\Big)$$

$$= \frac{\{(w_r - w_e)[(K^2 - (r-m)^2]\} + \{(w_r - w_{ex})[K_0^2 - K^2]\} - \{g[(r+m)^2 - (K_0)^2]\}}{4m} + \frac{\{[(w_{ex} - w_e)K](K_0 - K)\} + \{[(w_r - w_{ex} + g)K_0](r+m-K_0)\} + \{[(w_{ex} - w_e)K](r+m-K_0)\}}{2m} - K_0c_c + \frac{\{(w_e - c_p)[K^2 - (r-m)^2]\} + \{(w_{ex} - c_p)(K_0^2 - K^2)\}}{4m} + \frac{\{[(w_e - w_{ex})K](K_0 - K)\} + \{[(w_{ex} - c_p)K_0](r+m-K_0)\} + \{[(w_e - w_{ex})K](r+m-K_0)\}}{2m}$$

$$= \frac{[(w_r - w_e)K^2] - [(w_r - w_e)(r-m)^2] + [(w_r - w_{ex})K_0^2] - [(w_r - w_{ex})K^2] - \{g[(r+m)^2 - (K_0)^2]\}}{4m} + \frac{[(w_{ex} - w_e)KK_0] - [(w_{ex} - w_e)K^2] + \{[(w_r - w_{ex} + g)K_0](r+m-K_0)\} + \{[(w_{ex} - w_e)K](r+m-K_0)\}}{2m} - K_0c_c + \frac{[(w_e - c_p)K^2] - [(w_e - c_p)(r-m)^2] + [(w_{ex} - c_p)K_0^2] - [(w_{ex} - c_p)K^2]}{4m} + \frac{[(w_e - w_{ex})KK_0] - [(w_e - w_{ex})K^2] + \{[(w_{ex} - c_p)K_0](r+m-K_0)\} + \{[(w_e - w_{ex})K](r+m-K_0)\}}{2m}$$

$=\frac{[(w_r-w_e)K^2]-[(w_r-w_e)(r-m)^2]+[(w_r-w_{ex})K_0^2]-[(w_r-w_{ex})K^2]-\{g[(r+m)^2-(K_0)^2]\}}{4m}+$

$\frac{[(w_e-c_p)K^2]-[(w_e-c_p)(r-m)^2]+[(w_{ex}-c_p)K_0^2]-[(w_{ex}-c_p)K^2]}{4m}+$

$\frac{[(w_{ex}-w_e)KK_0]-[(w_{ex}-w_e)K^2]+\{[(w_r-w_{ex}+g)K_0](r+m-K_0)\}+\{[(w_{ex}-w_e)K](r+m-K_0)\}}{2m}+$

$\frac{[(w_e-w_{ex})KK_0]-[(w_e-w_{ex})K^2]+\{[(w_{ex}-c_p)K_0](r+m-K_0)\}+\{[(w_e-w_{ex})K](r+m-K_0)\}}{2m}-K_0c_c$

$=-K_0c_c+$

$\frac{[(w_r-w_e)K^2]-[(w_r-w_e)(r-m)^2]+[(w_r-w_{ex})K_0^2]-[(w_r-w_{ex})K^2]-\{g[(r+m)^2-(K_0)^2]\}}{4m}+$

$\frac{[(w_e-c_p-w_{ex}+c_p)K^2]-[(w_e-c_p)(r-m)^2]+[(w_{ex}-c_p)K_0^2]}{4m}+$

$\frac{\{[(w_r-w_{ex}+g)K_0](r+m-K_0)\}+\{[(w_{ex}-c_p)K_0](r+m-K_0)\}}{2m}$

$=-K_0c_c+\frac{[(w_r-w_e)K^2]-[(w_r-w_e)(r-m)^2]+[(w_r-w_{ex})K_0^2]-[(w_r-w_{ex})K^2]-\{g[(r+m)^2-(K_0)^2]\}}{4m}+$

$\frac{[(w_e-w_{ex})K^2]-[(w_e-c_p)(r-m)^2]+[(w_{ex}-c_p)K_0^2]}{4m}+$

$\frac{\{[(w_r-w_{ex}+g)K_0](r+m-K_0)\}+\{[(w_{ex}-c_p)K_0](r+m-K_0)\}}{2m}$

$=-K_0c_c+\frac{[(w_r-w_e-w_r+w_{ex}+w_e-w_{ex})K^2]+[(-w_r+w_e-w_e+c_p)(r-m)^2]}{4m}+$

$\frac{[(w_r-w_{ex}+w_{ex}-c_p)K_0^2]-\{g[(r+m)^2-(K_0)^2]\}}{4m}+\frac{\{[(w_r-w_{ex}+g+w_{ex}-c_p)K_0](r+m-K_0)\}}{2m}$

$=-K_0c_c+\frac{[(-w_r+c_p)(r-m)^2]+[(w_r-c_p)K_0^2]-\{g[(r+m)^2-(K_0)^2]\}}{4m}+\frac{\{[(w_r+g-c_p)K_0](r+m-K_0)\}}{2m}$

It is noted that $\pi_{DSC}(K,K_0)$ *depends only on* K_0.

3.5 The Optimal Constructed Capacity which Maximize the Total Profit of the Whole Supply Chain

$$\frac{d\pi_{DSC}}{dK_0}=-c_c+\frac{2(w_r-c_p)K_0+2gK_0}{4m}+\frac{(w_r-c_p+g)(r+m)-2(w_r+g-c_p)K_0}{2m}=-c_c+\frac{(w_r-c_p+g)K_0+(w_r-c_p+g)(r+m)-2(w_r-c_p+g)K_0}{2m}$$

$$=-c_c+\frac{(w_r-c_p+g)(r+m)-(w_r-c_p+g)K_0}{2m}$$

$$\frac{d^2\pi_{DSC}}{dK_0^2}=\frac{-(w_r-c_p+g)}{2m}$$

$$=\frac{c_p-w_r-g}{2m}$$

It is noted that $c_p-w_r-g<0$, the second derivative is negative,

$$\frac{d^2\pi_{DSC}}{dK_0^2}<0$$

So, $\pi(K_0)$ is a concave function with respect to K_0.

Then the optimal constructed capacity K_0 is the unique solution of $\frac{d\pi}{dK_0} = 0$. Hence,

$$\frac{d\pi_{DSC}}{dK_0} = -c_c + \frac{(w_r - c_p + g)(r+m) - (w_r - c_p + g)K_0}{2m} = 0$$
$$(w_r - c_p + g)(r + m) - (w_r - c_p + g)K_0 = 2mc_c$$
$$-(w_r - c_p + g)K_0 = 2mc_c - (w_r - c_p + g)(r + m)$$
$$K_0 = \frac{2mc_c - (w_r - c_p + g)(r+m)}{-(w_r - c_p + g)}$$
$$K_0 = r + m - \frac{2mc_c}{(w_r - c_p + g)}$$

It is noted that K_0 must be positive, therefore, the following condition must hold true:

$$r + m \geq \frac{2mc_c}{(w_r - c_p + g)}$$
$$So,\ K_{0c}^* = r + m - \frac{2mc_c}{(w_r - c_p + g)}$$

Decision Analysis:

It should be recalled that

The unconditional optimal solution of K is, $K^* = r + m - \frac{2mw_0}{(w_{ex} - w_e)}$

The unconditional optimal solution of K_0 is, $K_0^* = r + m - \frac{2mc_c}{w_{ex} - c_p}$

$$K_{0d}^* = \{K_0^*\ if\ K_0^* \geq K^*\ K^* if K_0^* < K^*$$

or

$$K_{0d}^* = Max\{K^*, K_0^*\}$$

So, in decentralized system:

- When the manufacturer is the leader:

$$K_{0d}^* = K_0^*$$

- When the retailer is the leader:

$$K_{0d}^* = Max\{K^*, K_0^*\}$$

3.6 Analysis of the Coordination of the Supply Chain

As a result of the derivations in the previous chapters, the optimal constructed capacities K_{0d}^* or K_{oc}^* are the amounts available for the whole supply chain in the decentralized and the centralized systems. If the constructed capacity of the manufacturer in the decentralized supply chain (K_{0d}^*)is equal to the constructed capacity in the centralized supply chain (K_{0d}^*), then it can be claimed that the whole supply chain is coordinated.

The following scenarios may occur in the decentralized system:

Scenario 1: when the manufacturer is the leader, he will decide on the constructed capacity and his decision is not affected by the reserved capacity of the retailer

So, for coordination to occur, we must have $K_{0c}^* = K_{0d}^* = K_0^*$.

- $r + m - \frac{2mc_c}{w_r - c_p + g} = r + m - \frac{2mc_c}{w_{ex} - c_p}$

Or equivalently

- $w_r + g = w_{ex}$

Scenario 2: when the retailer is the leader, he will decide on the reserved capacity, and the constructed capacity of the manufacturer must be at least equal to the reserved capacity of the retailer. So,

If $K_0^* \geq K^*$,then $K_{0d}^* = K_0^*$.

For coordination to occur, we must have $K_{0c}^* = K_{0d}^* = K_0^*$

So, the conditions for coordination in this case is:

- $r + m - \frac{2mc_c}{w_{ex} - c_p} \geq r + m - \frac{2mw_0}{w_{ex} - w_e}$ and
- $r + m - \frac{2mc_c}{w_r - c_p + g} = r + m - \frac{2mc_c}{w_{ex} - c_p}$

Or equivalently,

- $\frac{c_c(w_{ex} - w_e)}{w_{ex} - c_p} < w_0$ and
- $w_r + g = w_{ex}$

If K_{0*} <K*, then $K_{0d}^* = K^*$. For coordination to occur, we must have $K_{0c}^* = K_{0d}^* = K^*$

So, the condition for coordination in this case is:

- $r + m - \frac{2mc_c}{w_{ex} - c_p} < r + m - \frac{2mw_0}{w_{ex} - w_e}$ and
- $r + m - \frac{2mc_c}{w_r - c_p + g} = r + m - \frac{2mw_0}{w_{ex} - w_e}$

Or equivalently,

- $\frac{c_c(w_{ex}-w_e)}{w_{ex}-c_p} > w_0$ and
- $\frac{w_0(w_r-c_p+g)}{c_c} + w_e = w_{ex}$

CHAPTER 4
NUMERICAL EXPERIMENTS

In this section, a numerical instance is offered initially to exhibit ability of the developed mathematical model and to investigate two types of coordination scenarios. Following that, sensitivity analysis is carried out to look into the effects of input parameters (w_0, w_e, w_r, w_{ex}, c_c, c_p, g) on the optimal quantities (K, K_0) and profit functions of the proposed contract. Ideal values of objective function are determined using MATLAB software.

4.1 Numerical Experiment for Scenario One

The following values are used for the base case.

w_0 =20; Unit reservation price

w_e =100; Unit exercised price ($w_e < w_{ex}$)

w_{ex} =290; Unit excess exercise price ($w_{ex} > c_p$, $w_{ex} > w_e$, $w_r + g = w_{ex}$)

w_r =200; Unit selling price of retailer

c_c =5; Supplier's unit constructing cost

c_p =55; Supplier's unit production cost ($c_p < w_{ex}$)

g =90; Unit shortage cost

r =1000;

m =200;

It should be noted that the values were chosen to satisfy the following assumptions: $w_{ex} > c_p$, $w_{ex} > w_e$, $w_r + g = w_{ex}$ and demand follows a uniform distribution from 800 to 1200.

The solutions obtained by using MATLAB are as follows

Reserved capacity: K = 1158

Constructed capacity: K_0 = 1192

π^R = 76421; profit of retailer

$\pi^M = 62600$; profit of manufacturer

$\pi_{DSC} = \pi_{CSC} = 139021$; total profit of supply chain

4.1.1 Sensitivity Analysis

In this section, a sensitivity analysis is used in this part to examine contract input parameters' impact on decision variables and overall profitability of the buyer and vendor.

4.1.1.1 **Sensitivity Analysis with Respect to w_0** Table 4.1 presents effect of unit reservation price on profit of retailer and supplier, reserved capacity and constructed capacity. According to the results in Table 4.2, the retailer's capacity K decreases because of increasing unit reservation price but the construction capacity K_0 does not change. The manufacturer's profit increases when reservation price increases. The increase in reservation price is desirable for manufacturer but no for buyer. It should be noted that the price of the changed reservation has no impact on the decision on manufacturer's constructed capacity K_0.

Table 4.1

Effect of Unit Reservation Price on Profit of Retailer and Supplier, Reserved Capacity and Constructed Capacity

w_0	K	K_0	Retailer's profit	Manufacturer's profit
20	1158	1191	76421	62600
25	1147	1191	70658	68363
30	1136	1191	64947	74074
35	1126	1191	59289	79732
40	1116	1191	53684	85337

4.1.1.2 **Sensitivity Analysis with Respect to w_e** Table 4.2 presents consequence of unit exercised price on profits of buyer and vendor, reserved capacity and constructed capacity. According to the results in Table 4.2, as the unit exercised price increases, the retailer's reserved capacity K decreases. It is noted that the change in unit exercised price has no effects the manufacturer's capacity decision K_0. The manufacturer's total profit increases when exercised price increases. The increase in unit exercised price is beneficial to the manufacturer but no for retailer.

Table 4.2

Effect of Unit Exercised Price on Profits of Retailer and Supplier, Reserved Capacity and Constructed Capacity

w_e	K	K_0	Retailer's profit	Manufacturer's profit
100	1158	1191	76421	62600
105	1157	1191	71432	67589
110	1156	1191	66444	72577
115	1154	1191	61457	77564
120	1153	1191	56471	82551

4.1.1.3 **Sensitivity Analysis with Respect to w_r** Table 4.3 presents effect of unit selling price of retailer on profits of retailer and supplier, reserved capacity and constructed capacity. According to the results in Table 4.3, the reserved capacity K of the retailer and the constructed capacity K_0 of the vendor increases when the selling price raises. The total earnings of buyer and vendor enhances with the increasing unit selling price.

Table 4.3

Effect of Unit Selling Price of Retailer on Profits of Retailer and Supplier, Reserved Capacity and Constructed Capacity

w_r	K	K_0	Retailer's profit	Manufacturer's profit
200	1158	1191	76421	62600
205	1159	1192	81410	62611
210	1160	1192	86400	62620
215	1161	1192	91390	62630
220	1162	1192	96381	62631

4.1.1.4 **Sensitivity Analysis with Respect to c_c** Table 4.4 presents consequence of unit constructing cost of manufacturer on profit of buyer and vendor, reserved capacity, and constructed capacity. According to the results in Table 4.4, the manufacturer's constructed capacity K_0 decreases when c_c increases, and since, vendor's earnings decrease. There is no change in reserved capacity K and retailer's profit.

Table 4.4

Effect of Unit Constructing Cost of Manufacturer on Profit of Retailer and Supplier, Reserved Capacity and Constructed Capacity

c_c	K	K_0	Retailer's profit	Manufacturer's profit
5	1158	1191	76421	62600
10	1158	1183	76421	56664
15	1158	1174	76421	50770
20	1158	1166	76421	44919
25	1158	1157	76421	39111

4.1.1.5 **Sensitivity Analysis with Respect to c_p** Table 4.5 presents consequence of unit producing cost of manufacturer on profit of buyer and vendor, reserved capacity and constructed capacity. According to the results in Table 4.5, there is no effect on reserved capacity K of retailer but the capacity of manufacturer K_0 decreases. The vendor's total earnings reduces whilst the buyer's earnings remains constant when c_p grows.

Table 4.5

Effect of Unit Production Cost of Manufacturer on Profits of Retailer and Supplier, Reserved Capacity and Constructed Capacity

c_p	K	K_0	Retailer's profit	Manufacturer's profit
55	1158	1191	76421	62600
60	1158	1191	76421	57601
65	1158	1191	76421	52601
70	1158	1191	76421	47602
75	1158	1191	76421	42602

4.1.1.6 **Sensitivity Analysis with Respect to g** Table 4.6 presents consequence of unit shortage cost on profit of retailer and supplier, reserved capacity and constructed capacity. According to the results in Table 4.6, the reserved capacity K increases when g raises while the retailer's total profit reduces. The unit shortage cost does not affect much on the constructed capacity of the manufacturer K_0. The manufacturer's total profit also increases with the increase of g.

Table 4.6

Effect of Unit Shortage Cost on Profit of Retailer and Supplier, Reserved Capacity and Constructed Capacity

g	K	K_0	Retailer's profit	Manufacturer's profit
90	1158	1191	76421	62600
95	1159	1192	76410	62611
100	1160	1192	76400	62620
105	1161	1192	76390	62630
110	1162	1192	76381	62639

4.2 Numerical Experiment for Scenario Two

There are two types in scenario two.

In first case, when the optimal constructed capacity exceeds the optimal reserved capacity, the optimal constructed capacities in decentralized system should equal to that of centralized system for coordination to occur.

The following values are used for the base case for the first case.

w_0 =50; Unit reservation price ($w_0 > \frac{c_c\left(w_{ex} - w_e\right)}{w_{ex} - c_p}$)

w_e =120; Unit exercised price

w_{ex} =370; Unit excess exercise price ($w_{ex} > c_p$, $w_{ex} > w_e$, w_r+g= w_{ex})

w_r =250; Unit selling price of retailer

c_c =20; Supplier's unit constructing cost

c_p =80; Supplier's unit production cost

g =120; Unit shortage cost

r =1000;

m =200;

It is noted that the values are selected such that the following assumptions are satisfied:

$w_{ex} > c_p$, $w_{ex} > w_e$, $w_0 > \frac{c_c\left(w_{ex}-w_e\right)}{w_{ex}-c_p}$ and $w_{ex} = w_r + g$

and demand follows a uniform distribution from 800 to 1200.

The solutions obtained by using MATLAB are as follows

Reserved capacity: K = 1120

Constructed capacity: K_0 = 1172

π^R = 72000; profit of retailer

π^M = 74276; profit of manufacturer

$\pi_{DSC}=\pi_{CSC}$ = 146276; total profit of supply chain

4.2.1 Sensitivity Analysis

Sensitivity analysis is used in this part to examine the impact of contract input parameters on decision variables and overall profitability of the retailer and supplier.

4.2.1.1 **Sensitivity Analysis with Respect to w_r** Table 4.7 presents consequence of unit selling price of retailer on profit of retailer and supplier, reserved capacity and constructed capacity**.** According to the results in Table 4.7, the retailer's reserved capacity K and the constructed capacity K_0 increases because of increasing unit reservation pricing. The manufacturer's total earning increases and the retailer's total earning increases when reservation price increases.

Table 4.7

Effect of Unit Selling Price of Retailer on Profit of Retailer and Supplier, Reserved Capacity and Constructed Capacity

w_r	K	K_0	Retailer's profit	Manufacturer's profit
250	1120	1172	72000	74276
255	1122	1173	76961	74310
300	1133	1176	121667	74569
350	1143	1179	171429	74777
355	1144	1180	176409	74794

***4.2.1.2* Sensitivity Analysis with Respect to w_e** Table 4.8 presents consequence of unit exercised price on profit of buyer and vendor, reserved capacity and constructed capacity. According to the results in Table 4.8, as the unit exercised price is higher, the retailer's reserved capacity K decreases. It is noted that the change in unit exercised price will not affect the manufacturer's capacity selection K_0. The manufacturer's total profit increases when exercised price increases. For the manufacturer, an increase in unit exercised price is desirable, but not for the retailer.

Table 4.8

Effect of Unit Exercised Price on Profit of Retailer and Supplier, Reserved Capacity and Constructed Capacity

w_e	K	K_0	Retailer's profit	Manufacturer's profit
120	1120	1172	72000	74276
125	1118	1172	67041	79235
130	1117	1172	62083	84193
135	1115	1172	57128	89148
140	1113	1172	52174	94102

***4.2.1.3* Sensitivity Analysis with Respect to c_c** Table 4.9 presents consequence of unit constructing cost of manufacturer on earnings of retailer and supplier, reserved capacity and constructed capacity. According to the results in Table 4.9, the manufacturer's construction capacity K_0 decreases when c_c increases, and hence, the manufacturer's profit decreases. There is no change in reserved capacity K and retailer's profit.

Table 4.9

Effect of Unit Constructing Cost of Manufacturer on Profit of Retailer and Supplier, Reserved Capacity, and Constructed Capacity

c_c	K	K_0	Retailer's profit	Manufacturer's profit
20	1120	1172	72000	74276
25	1120	1166	72000	68431
30	1120	1159	72000	62621
35	1120	1152	72000	56845
40	1120	1145	72000	51103

***4.2.1.4* Sensitivity Analysis with Respect to c_p** Table 4.10 presents consequence of unit production cost of manufacturer on earnings of buyer and vendor, reserved capacity and constructed capacity. According to the results in Table 5, there is no effect in reserved capacity K of retailer but the constructed capacity of manufacturer K_0 decreases. The manufacturer's total earnings reduce whilst the vendor's total earnings remains constant when c_p grows.

Table 4.10

Effect of Unit Production Cost of Manufacturer on Profit of Retailer and Supplier, Reserved Capacity and Constructed Capacity

c_p	K	K_0	Retailer's profit	Manufacturer's profit
80	1120	1172	72000	74276
85	1120	1172	72000	69281
90	1120	1171	72000	64286
95	1120	1171	72000	59291
100	1120	1170	72000	54296

4.2.1.5* Sensitivity Analysis with Respect to *g Table 4.11 presents effect of unit shortage cost on profit of retailer and supplier, reserved capacity and constructed capacity. According to the results in Table 5.1, the unit shortage cost does not affect the reserved capacity K and the constructed capacity K_0 of the manufacturer. The retailer's profit decreases with the increase of g but the manufacturer's total profit remains constant.

Table 4.11

Effect of Unit Shortage Cost on Profits of Retailer and Supplier, Reserved Capacity and Constructed Capacity

g	K	K_0	Retailer's profit	Manufacturer's profit
120	1120	1172	72000	74276
125	1120	1172	71995	74276
130	1120	1172	71990	74276
135	1120	1172	71986	74276
140	1120	1172	71981	74276

In second case, when the optimal constructed capacity is less than the optimal reserved capacity, the optimal constructed capacity in centralized system should balance to the optimal constructed capacity in decentralized system and the optimal reserved capacity for coordination to occur.

The following values are used for the base case for the second case.

w_0 =5.4; Unit reservation price ($w_0 < \frac{c_c(w_{ex}-w_e)}{w_{ex}-c_p}$, $w_0 = \frac{c_c(w_{ex}-w_e)}{w_r-c_p+g}$)

w_e =120; Unit exercised price

w_{ex} =200; Unit excess exercise price ($w_{ex} > c_p$, $w_{ex} > w_e$)

w_r =250; Unit selling price of retailer

c_c =20; Supplier's unit constructing cost

c_p =80; Supplier's unit production cost

g =125; Unit shortage cost

r =1000;

m =200;

It is noted that the values are selected such that the following assumptions are satisfied:

$$w_{ex} > c_p,\ w_{ex} > w_e,\ w_0 < \frac{c_c(w_{ex}-w_e)}{w_{ex}-c_p},\ w_0 = \frac{c_c(w_{ex}-w_e)}{w_r-c_p+g}$$

and demand follows a uniform distribution from 800 to 1200.

The solutions obtained by using MATLAB are as follows

Reserved capacity: K = 1173

Constructed capacity: K_0 = 1133

π^R = 122593; profit of retailer

π^M = 23102; profit of manufacturer

$\pi_{DSC}=\pi_{CSC}$ = 146276; total profit of supply chain

4.2.2 Sensitivity Analysis

Sensitivity analysis is used in this part to examine the impact of contract input parameters on decision variables and overall profitability of the retailer and supplier.

4.2.2.1 **Sensitivity Analysis with Respect to w_r** Table 4.12 presents consequence of unit selling price of retailer on profit of retailer and supplier, reserved capacity and constructed capacity. According to the results in Table 5.3, the reserved capacity K of the retailer increases because of increasing unit reservation price but the constructed capacity K_0 doesn't change. As the reserved capacity increases, the retailer's profit increases. But the construction capacity is constant, so the manufacturer's profit will not increase.

Table 4.12

Effect of Unit Selling Price of Retailer on Profit of Retailer and Supplier, Reserved Capacity and Constructed Capacity

w_r	K	K_0	Retailer's profit	Manufacturer's profit
250	1173	1133	122593	23102
255	1173	1133	127671	22996
260	1174	1133	132746	22893
265	1174	1133	137818	22794
270	1175	1133	142886	22697

4.2.2.2 **Sensitivity Analysis with Respect to w_r** Table 4.13 presents effect of unit exercised price on profit of retailer and supplier, reserved capacity and constructed capacity. According to the results in Table 5.4, as the unit exercised price is higher, both the buyer's reserved capacity K and the vendor's constructed capacities remain constant. The manufacturer's total profit increases when exercised price increases but the profit of the retailer decreases.

Table 4.13

Effect of Unit Exercised Price on Profit of Retailer and Supplier, Reserved Capacity and Constructed Capacity

w_e	K	K_0	Retailer's profit	Manufacturer's profit
120	1173	1133	122593	23102
125	1173	1133	117995	27699
130	1173	1133	113397	32297
135	1173	1133	108799	36895
140	1173	1133	104202	41493

4.2.2.3 **Sensitivity Analysis with Respect to w_{ex}** Table 4.14 presents effect of unit excess exercise price of retailer on profit of retailer and supplier, reserved capacity and constructed capacity. According to the results in Table 5.4, the reserved capacity K of the retailer remains constant and the constructed capacity K_0 of the manufacturer increases when the excess exercise price increases. The retailer's total earnings decreases, and the vendor's total earnings increases.

Table 4.14

Effect of Unit Excess Exercise Price of Retailer on Profit of Retailer and Supplier, Reserved Capacity and Constructed Capacity

w_{ex}	K	K_0	Retailer's profit	Manufacturer's profit
200	1173	1133	122593	23102
205	1173	1136	122293	23477
210	1173	1138	121980	23855
215	1173	1141	121656	24234
220	1173	1143	121324	24615

4.2.2.4 **Sensitivity Analysis with Respect to c_c** Table 4.15 presents effect of unit constructing cost of manufacturer on profit of retailer and supplier, reserved capacity, and constructed capacity. According to the results in Table 5.6, the manufacturer's constructed capacity K_0 decreases when c_c increases, likewise, the reserved capacity K also decreases. The earnings of retailer and the earnings of vendor both drops.

Table 4.15

Effect of Unit Constructing Cost of Manufacturer on Profit of Retailer and Supplier, Reserved Capacity, and Constructed Capacity

c_c	K	K_0	Retailer's profit	Manufacturer's profit
20	1173	1133	122593	23102
25	1166	1117	120460	19062
30	1159	1100	118215	15097
35	1153	1083	115858	11206
40	1146	1067	113388	7389

4.2.2.5 **Sensitivity Analysis with Respect to c_p** Table 4.16 presents consequence of unit production cost of manufacturer on profits of retailer and supplier, reserved capacity, and constructed capacity. According to the results in Table 5.7, the reserved capacity K and the constructed capacity decrease when the unit production cost raises. As the capacities they reserve/construct are reduced, the vendor's overall earnings declines, while the buyer's total earnings also decline.

Table 4.16

Effect of Unit Production Cost of Manufacturer on Profit of Retailer and Supplier, Reserved Capacity and Constructed Capacity

c_p	K	K_0	Retailer's profit	Manufacturer's profit
80	1173	1133	122593	23102
85	1172	1130	122397	18240
90	1172	1127	122185	13385
95	1171	1124	121955	8537
100	1171	1120	121703	3697

4.2.2.6 **Sensitivity Analysis with Respect to g** Table 4.17 presents effect of unit shortage cost on profits of retailer and supplier, reserved capacity and constructed capacity. According to the results in Table 5.8, the reservation capacity K increases when g increases while the constructed capacity remain constant. The unit shortage cost does not affect on the constructed capacity of the manufacturer K_0. The buyer's total earnings also raise with the increase of g, on the other hand, the manufacturer's profit decreases.

Table 4.17

Effect of Unit Shortage Cost on Profits of Retailer and Supplier, Reserved Capacity, and Constructed Capacity

g	K	K_0	Retailer's profit	Manufacturer's profit
125	1173	1133	122593	23102
130	1173	1133	122671	22996
135	1174	1133	122746	22893
140	1174	1133	122818	22794
145	1175	1133	122886	22697

CHAPTER 5
CONCLUSIONS AND RECOMMANDATIONS

This research developed the capacity reservation contract with a vendor and a buyer. In considered contract model, the supplier might will construct different capacity from the reserved capacity of retailer. There is no savage value in the remaining created capacity. Ahead the time of selling season, the buyer will reserve capacity with reservation fee under uncertain demand. In the selling season, the buyer will exercise capacity based on realized demand.

This research created a mathematical model to account for real-time demand fluctuations in profit functions for retailers, manufacturers, and the entire supply chain. From the model that has been constructed, the optimal constructed capacities are investigated for the whole supply network in decentralized system and centralized system.

When the vendor's constructed capacity in the decentralized supply chain meets the vendor's constructed capacity in the centralized supply chain, the entire supply chain is said to be coordinated. The mathematical model was validated using numerical analysis and sensitivity analysis. We can see from the numerical findings that the proposed contract can help coordinate the supply chain under certain conditions.

Furthermore, we may deduce if a well coordination scenario in the supply chain can boost profit of the supply chain. The performance of the suggested contract in terms of revenue sharing should be examined for future research. Also, because our study focused on a single vendor and one retailer, a study involving one supplier and numerous retailers could result in a capacity reservation contract.

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APPENDIX

MATLAB code to conduct numerical experiments for coordination

Scenario one

```
%Proposed bidirectional option contract
clear all;
syms K K0 K0c z;

w_0 =20;%Unit reservation price
w_e =100;%Unit exercised price(w_e<w_ex)
w_ex =290;%Unit excess exercise price(w_ex>c_p, w_ex>w_e, w_r+g=
w_ex)
w_r =200;%Unit selling price of retailer
c_c =5;%Supplier's unit constructing cost
c_p =55;%Supplier's  unit production cost
g =90;%Unit shortage cost
r =1000;%demand range
m =200;%demand range

%Retailer's profit
r1=int(((w_r*z-w_e*z)/(2*m)),z,r-m,K);
r2=int((((w_r*z-w_e*K-w_ex*(z-K)))/(2*m)),z,K,K0);
r3=int(((w_r*K0-w_e*K-w_ex*(K0-K)+g*K0-g*z)/(2*m)),z,K0,r+m);
R=r1+r2+r3;
pf_R=R-(w_0*K);

%Manufacturer's profit
m1=int(((w_e*z-c_p*z)/(2*m)),z,r-m,K);
m2=int(((w_e*K+w_ex*(z-K)-c_p*z)/(2*m)),z,K,K0);
m3=int(((w_e*K+w_ex*(K0-K)-c_p*K0)/(2*m)),z,K0,r+m);
M=m1+m2+m3;
pfM=(M-K0*c_c+w_0*K);
%SCprofit function
SC=pf_R+pfM;

%Find the optimal solution
pf_1 = diff(pf_R,'K');
pf_2 = diff(pfM,'K0');
pf_3 = diff(SC,'K0');
S = solve([pf_1==0,pf_2==0, pf_3==0],[K,K0,K0c]);
K1 = double(vpa(S.K));
K01 = double(vpa(S.K0));
K02 = double(vpa(S.K0));


% ========== for K =====================
if K1<=K01
    K=K1;
elseif K1>K01
    K=K01;
end

% ========== for K0 =====================
if K01>=K1
    K0=K01;
elseif K01<K1
```

```
    K0=K1;
end
% ========== for K0c ====================
K0c=K02
format ShortG
K
K0
K0c

pfr = double(subs(pf_R))
pfm = double(subs(pfM))
sc = double(subs(SC))
Koc= double(subs(K02))
```

MATLAB code to conduct numerical experiments for coordination

First case of scenario two

```
%Proposed bidirectional option contract
clear all;
syms K K0 K0c z;

w_0 =50;%Unit reservation price
w_e =120;%Unit exercised price(w_e<w_ex)
w_ex =370;%Unit excess exercise price(w_ex>c_p, w_ex>w_e, w_r+g=
w_ex)
w_r =250;%Unit selling price of retailer
c_c =20;%Supplier's unit constructing cost
c_p =80;%Supplier's  unit production cost
g =120;%Unit shortage cost
r =1000;%demand range
m =200;%demand range

%Retailer's profit
r1=int(((w_r*z-w_e*z)/(2*m)),z,r-m,K);
r2=int((((w_r*z-w_e*K-w_ex*(z-K)))/(2*m)),z,K,K0);
r3=int(((w_r*K0-w_e*K-w_ex*(K0-K)+g*K0-g*z)/(2*m)),z,K0,r+m);
R=r1+r2+r3;
pf_R=R-(w_0*K);

%Manufacturer's profit
m1=int(((w_e*z-c_p*z)/(2*m)),z,r-m,K);
m2=int(((w_e*K+w_ex*(z-K)-c_p*z)/(2*m)),z,K,K0);
m3=int(((w_e*K+w_ex*(K0-K)-c_p*K0)/(2*m)),z,K0,r+m);
M=m1+m2+m3;
pfM=(M-K0*c_c+w_0*K);
%SCprofit function
SC=pf_R+pfM;

%Find the optimal solution
pf_1 = diff(pf_R,'K');
pf_2 = diff(pfM,'K0');
pf_3 = diff(SC,'K0');
S = solve([pf_1==0,pf_2==0, pf_3==0],[K,K0,K0c]);
K1 = double(vpa(S.K));
K01 = double(vpa(S.K0));
K02 = double(vpa(S.K0));
```

```
% ========== for K =====================
if K1<=K01
    K=K1;
elseif K1>K01
    K=K01;
end

% ========== for K0 =====================
if K01>=K1
    K0=K01;
elseif K01<K1
    K0=K1;
end
% ========== for K0c ====================
K0c=K02
format ShortG
K
K0
K0c

pfr = double(subs(pf_R))
pfm = double(subs(pfM))
sc = double(subs(SC))
Koc= double(subs(K02))
```

MATLAB code to conduct numerical experiments for coordination

Second case of scenario two

```
%Proposed bidirectional option contract
clear all;
syms K K0 K0c z;

w_0 =5.4;%Unit reservation price
w_e =120;%Unit exercised price
w_ex =200;%Unit excess exercise price
w_r =250;%Unit selling price of retailer
c_c =20;%Supplier's unit constructing cost
c_p =80;%Supplier's  unit production cost
g =125;%Unit shortage cost
r =1000;%demand range
m =200;%demand range

%Retailer's profit
r1=int(((w_r*z-w_e*z)/(2*m)),z,r-m,K);
r2=int((((w_r*z-w_e*K-w_ex*(z-K)))/(2*m)),z,K,K0);
r3=int(((w_r*K0-w_e*K-w_ex*(K0-K)+g*K0-g*z)/(2*m)),z,K0,r+m);
R=r1+r2+r3;
pf_R=R-(w_0*K);

%Manufacturer's profit
m1=int(((w_e*z-c_p*z)/(2*m)),z,r-m,K);
m2=int(((w_e*K+w_ex*(z-K)-c_p*z)/(2*m)),z,K,K0);
m3=int(((w_e*K+w_ex*(K0-K)-c_p*K0)/(2*m)),z,K0,r+m);
M=m1+m2+m3;
pfM=(M-K0*c_c+w_0*K);
%SCprofit function
SC=pf_R+pfM;
```

```
%Find the optimal solution
pf_1 = diff(pf_R,'K');
pf_2 = diff(pfM,'K0');
pf_3 = diff(SC,'K0');
S = solve([pf_1==0,pf_2==0, pf_3==0],[K,K0,K0c]);
K1 = double(vpa(S.K));
K01 = double(vpa(S.K0));
K02 = double(vpa(S.K0));


% ========== for K =====================
if K1<=K01
    K=K1;
elseif K1>K01
    K=K01;
end

% ========== for K0 =====================
if K01>=K1
    K0=K01;
elseif K01<K1
    K0=K1;
end
% ========== for K0c ====================
K0c=K02
format ShortG
K
K0
K0c

pfr = double(subs(pf_R))
pfm = double(subs(pfM))
sc = double(subs(SC))
Koc= double(subs(K02))
```